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Non-stationary corona around multi-electrode system in external electric field

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A non-stationary corona in which the front of space charge has not bridged the gap is studied by considering a multi-electrode equipotential system in an unsteady electric field. Onset electric field and the evolution in time of discharge characteristics (discharge current, injected space charge, etc.) are numerically calculated versus the distance between electrodes. Conditions are obtained that corona near a real multi-electrode system can be simulated by charge emission from a plane in an electric field exceeding some threshold.

1. Introduction

A corona discharge developed from a system of closely-spaced equipotential electrodes occurs under natural conditions (point discharges at the tips of trees, bushes, leaves, grasses and other sharp objects under thunderstorm conditions) and in engineering practice.
A plane which emits ions in an unsteady external electric field exceeding some threshold, $E_{0\ cor}$, can be considered as a limiting case of a real plane system with numerous identical coronating points. Such an emitting plane has the following unique properties. (i) The current density through the plane, j, is controlled only by the rise rate of an external electric field E_0 ($j = \varepsilon_0 \partial E_0/\partial t$, where ε_0 is the gas permittivity) and is independent of the ion mobility. (ii) Space charge injected into the gap from a unit plane area cannot be higher than $\sigma_{max}=\varepsilon_0 E_{0\ max}$, where $E_{0\ max}$ is the maximum external electric field. (iii) Due to charge injection, the electric field on the plane is maintained at a constant level equal to the onset threshold $E_{0\ cor}$.
The purpose of this work is to determine conditions that a corona ignited near a real multi-electrode system in an unsteady external electric field behaves similarly to an emitting plane.

2. Computer model

A large number (>5000) of identical electrodes are assumed to be uniformly distributed over a conductive plane. Each electrode, being a grounded hemisphere of radius r_0, is placed at height h above the plane. The distance between adjacent electrodes is D. The effect of the charge of grounding conductor is neglected in calculating the electric field and corona characteristics; that is, the conductor is assumed to be infinitely thin. A corona is ignited in a uniform electric field $E_0(t)$.
The discharge is described by the balance equations for the ion densities and Poisson's equation. The boundary condition is that the electric field near the coronating surfaces is equal to corona onset field. Light molecular ions and aerosol ions are considered; their mobilities and rate of ion conversion are taken from [1]. The initial density of neutral aerosol particles is assumed to be 10^5 cm^{-3}.
Our calculations include two steps: the determination of onset external electric field and calculation of corona characteristics.

3. Conditions for corona ignition

The external electric field $E_{0\ cor}$ in which a corona is ignited near the electrode tops depends on the ratios h/r_0 and D/h. Our calculations show that the onset field $E_{0\ cor}$ for the multi-electrode system is close to that for the solitary electrode at $D/h>2$. The value of $E_{0\ cor}$ increases as the distance between electrodes decreases. This is explained by a screening effect of the charges located on adjacent electrodes. As a result, the onset field triples at $D/h = 0.25$.

4. Results

An external uniform electric field E_0 above the plane is assumed to rise linearly with a rate of 0.9 kVm^{-1}s^{-1} from an onset field of $E_{0cor} = 2.1$ kVm^{-1} for $0 < t < 20$ s and is constant for $t > 20$ s. Figure 1 shows the evolution in time of the corona current from a given electrode in the system for $h = 10$ m, $r_0 = 5$ cm and various D. Each curve is normalized to its own maximum corona current $I_{max} = i\,(t = 20$ s).
In the case of a solitary hemispherically tipped electrode, the current of non-stationary corona must (i) increase linearly with time when E_0 rises linearly with time and (ii) decrease as $i \sim t^{-1/2}$ when E_0 is time-independent [2]. In figure 1, curve 1 shows that, at large ratios D/h, each electrode in the system behaves as a solitary electrode. In a multi-electrode system with small values of D/h, the corona current must (i) be constant when E_0 rises linearly with time and (ii)

decline steeply down to zero when E_0 is constant. Figure 1 shows that our calculations for small D/h correlate well with such an evolution in time of the current. Here, the calculated current rises only in the beginning until the ion clouds developed from individual electrodes unite into one common space charge layer. At intermediate D/h, the curves also behave in an intermediate way.

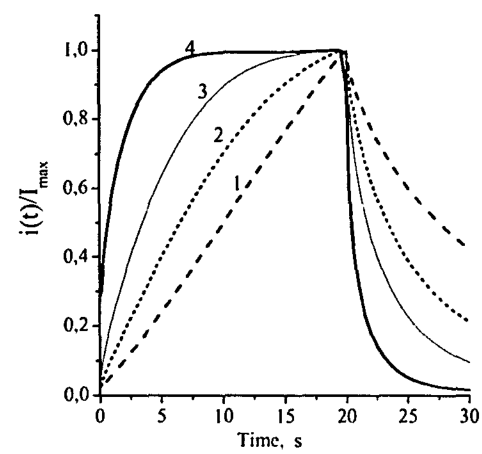

Fig. 1. The evolution in time of the corona current from a given electrode in the system with D/h = (1) 5, (2) 3, (3) 2, and (4) 1. The values of I_{max} correspond to 0.88; 3.53, 7.55; and 14.5 μA, respectively.

It is known that the injection of space charge into the gap leads to the electric field stabilization near a coronating surface. The same effect is likely near the plane covered with a large number of electrodes once the individual ion clouds have united into one plane space charge layer.

Figure 2 shows the evolution in time of the electric field on the plane under a given hemispherical electrode for various D/h. The front of space charge developed from any electrode tip covered distances of 35-40 m for 20 s. The electric field on the plane has not stabilized for D/h = 5, whereas this field stopped to rise and was close to $E_{0\ cor}$ already at t > 3 s after the corona ignition for D/h = 1. Hence it follows that, under thundercloud conditions, the measurement of the electric field on the ground surface covered with numerous coronating points provides an information about the onset threshold for such a multi-point system rather than about the electric field strength of a thundercloud.

Unlike the case of a steady corona, the current of non-stationary corona is not proportional to the ion mobility μ. The more non-uniform is the undisturbed electric field in front of the expending space charge cloud the stronger is the effect of μ. For instance, an increase in μ by a factor of four must (i) lead to doubling the current in the case of a solitary spherical electrode [2] and (ii)

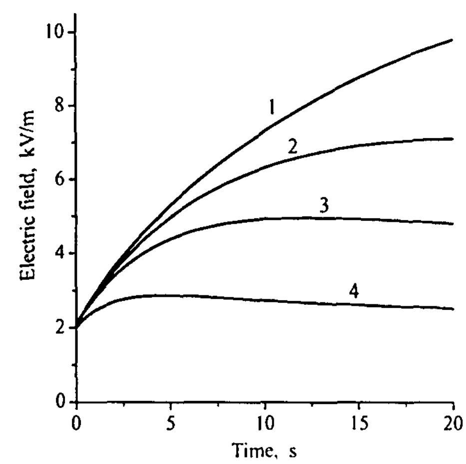

Fig. 2. The evolution in time of the electric field on the plane under a given hemispherical electrode for D/h = (1) 5, (2) 3, (3) 2, and (4) 1. The curves correspond to the same conditions as those in Fig. 1.

affect the current of a multi-electrode system only in the beginning of the process until the individual ion clouds unite into one space charge layer; thereafter, the current is independent of μ ($j = \varepsilon_0 \partial E_0/\partial t$). Consequently, the effect of μ can vary in time, in agreement with results given in figure 3 which shows the ratio of the calculated corona currents at μ = 6.0 and 1.5 $cm^2V^{-1}s^{-1}$. The calculations were made for a solitary electrode and the electrode system with D = 10 m.

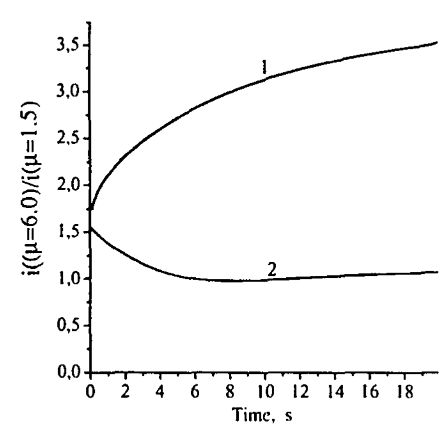

Fig. 3. Ratio of the calculated corona currents at μ = 6.0 and 1.5 $cm^2V^{-1}s^{-1}$. The calculations were made for (1) a solitary electrode and (2) the electrode system with D = 5 m.

5. References

[1] S. Chauzy and C. Rennela, *J. Geophys. Res.*, **90** (1985) 6051.

[2] N. Aleksandrov, E.M. Bazelyan, R.B. Carpenter et al, *J.Phys. D: Appl.Phys.*, **34** (2001) 3256.